exceptional extent and intensity almost in the center of the continent. Although the cyclone is figured as having two centers, one of 29.00 inches, the other of 29.05 inches one can not but wonder whether the real center is at either point. The cyclone extends in an east-west direction about 1,700 miles and in a north-south direction about 2,200 miles.

By the morning of the 26th the upper-air winds at 1,500 meters have changed from southerly to westerly as far east as the Atlantic coast. The velocities ranged from 10 to 20 m.p.s. At 3,000 meters still higher speeds were found, the maximum being 36 m.p.s. at Jacksonville, Fla., on the outskirts of the cyclone. The two centers shown on the chart for the 26th had disappeared by the morning of the 27th and pressure at the cyclone center had risen somewhat. Its course thence to the northeast was uneventful.—*A. J. Henry.*

GULF STREAM DAILY THERMOGRAMS ACROSS THE STRAITS OF FLORIDA[1]

By CHARLES F. BROOKS

[Clark University, Worcester, Mass., April 5, 1930]

SYNOPSIS

During the past four years the Gulf Stream has been subjected to investigation by sea-water thermographs on crossing ships. Details of temperature, including alternating masses of warmer and cooler water, diurnal ranges of temperature, and rapid changes in distribution, have been written on the thermograms to form an amazingly complex picture.

The thermograph is a mercury-in-steel bulb and capillary type, the thermal element being fixed in the intake pipe through which large volumes of water from several feet below the surface are continually pumped to the condensers.

An instrument of this sort installed in 1928 on the Peninsular & Occidental steamship *Henry M. Flagler*, one of the three Key West-to-Habana car ferries, provides the temperature record for one round trip daily while the ship is in operation. The southbound trip gives a night profile and the northbound a daytime one. From night to day in sunny quiet weather the sea temperature at the surface rises 3° or 4° F. and at a depth of 6 feet about 2°. In windy weather the diurnal range is reduced by stirring to 1° or less.

The summer profile is characteristically warmer in the north than in the south, while the temperature of Key West Harbor stands out several degrees above the Gulf Stream. A band of cool water is almost always traversed within a mile of the Cuban shore, apparently where swell and current striking the steeply sloping bottom bring cool water to the surface. Similar cool water often occurs likewise at the margin of shoal water south of Key West. The winter profile is usually 2° or more warmer in the south than in the north portion of the straits. A narrow zone of probably upwelling water several degrees cooler than on either side usually divides the warmer water from the cooler. This boundary shifts many miles with wind and other effects that bring at one time more water direct from the Caribbean and at another time from the Gulf. Great variations sometimes occur in the course of a few hours.

Storms, chiefly through their stirring action, reduce the surface temperatures by 1° or more. Strong cold winds have an even greater effect than hurricanes, for they chill the water considerably as well as mix the warm surface layer with the cooler substrata.

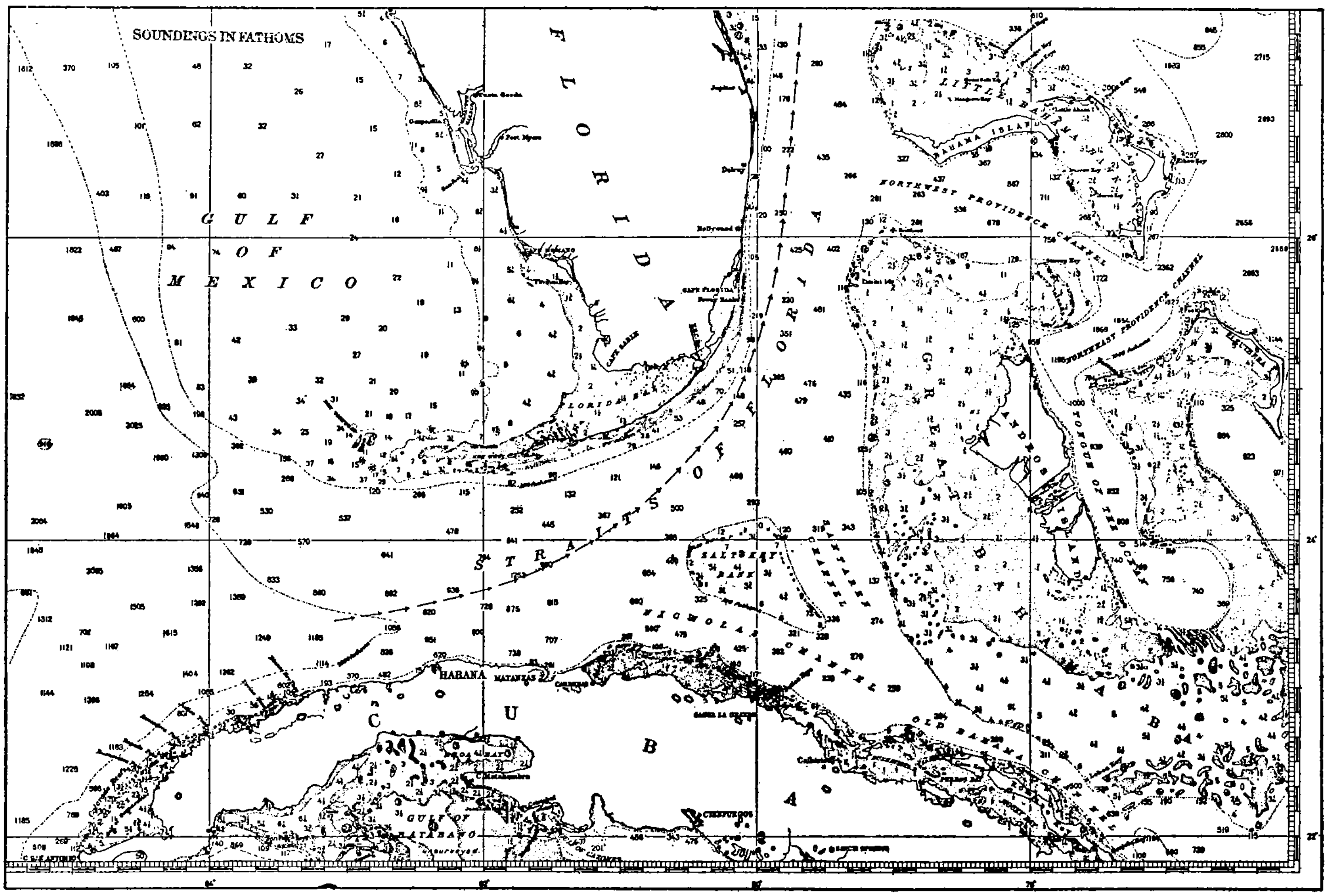


FIGURE 1.—Hydrographic features of the Gulf Stream within the Straits of Florida. (Adapted from United States Coast and Geodetic Survey Chart 1007 by the American Geographical Society for the *Geographical Review*, July, 1929.)

[1] Enlarged from paper presented at meetings of the American Meteorological Society, Des Moines, Iowa, Dec. 27, 1929, and the Association of American Geographers, Columbus, Ohio, Dec. 30, 1929. This is the first of a series of papers on The Gulf Stream and the Weather. (Cf. Gulf Stream Studies: General Meteorological Project, in the issue of the REVIEW of March, 1930.)

STRAITS OF FLORIDA SEA-SURFACE TEMPERATURE DATA HERETOFORE AVAILABLE

Observations of surface temperature made with the aid of canvas buckets are available for many years, both from ships passing through the straits and from the car ferries crossing them, but the spotty character and inherent inaccuracies prevent these data from being so informative as a continuous thermograph record.[2, 3] Therefore, the thermograph record, beginning July, 1928, brief though it is, should be studied before any extensive reduction of the other data is attempted. Furthermore, the thermograph record may be used as a standard by which the bucket observations can be judged, both as to their accuracy and as to their adequacy, in showing the general surface temperatures of the Gulf Stream here. The special series of observations at certain intervals across the straits made by officers of the Peninsular & Occidental Steamship Co. car ferries *Henry M. Flagler* and *Joseph R. Parrott*, 1917–1921, were resumed in 1928, under essentially the same conditions, on these ships and the *Estrada Palma*. Thus the earlier series may be evaluated on the basis of the relation of the later one to the thermograph record. The usual bucket observations made on ships passing through the straits have continued practically unchanged, except as to number, for decades. These data, however, are almost exclusively from the left half of the stream, largely in the more quiet waters near the Florida coast and reefs. (See map, fig. 1.) The car-ferry and other ships' bucket records will be analyzed in later papers

THE SEA-WATER THERMOGRAPH AND WHAT IT RECORDS

The opportunity for obtaining a detailed record of daily temperature across the Straits of Florida between Key West and Habana led the American Meteorological Society to grant $188 for the purchase (including the 40 per cent duty) of a large-scale Negretti & Zambra sea-water thermograph. This was delivered in April, 1928, exhibited at the meeting of the society held that month, then turned over to the United States Weather Bureau, under whose immediate auspices the instrument was to be installed on a ship at Key West, Fla. Mr. H. B. Boyer, the bureau's official in charge there, had previously obtained permission of the Peninsular & Occidental Steamship Co. to place the instrument in one of its vessels. Installation on the regularly running passenger ship *Governor Cobb* proving impracticable, the instrument was finally put into car ferry *Henry M. Flagler*, W. I. Jackson, master, by Curtis H. Stanton, chief engineer, who was very much interested. The first record was obtained July 8, 1928. The loss of an opportunity to obtain a regular record on the passenger ship was compensated by getting the nighttime as well as daytime observations and by other advantages. The more nearly surface temperatures obtained on the car ferry than could be got on another ship shows the diurnal changes more prominently. Furthermore, the longer period special series of bucket observations on the *Flagler* could now be compared directly with the new thermograph intake record on the same ship. Unfortunately, however, each car ferry is laid up at not infrequent intervals for a month at a time. So, rather long gaps in the record were to be expected. It has not seemed feasible to move the instrument from one ship to another to avoid these periods of idleness. Instead, the purchase of thermographs for the other two car ferries is hoped for.

The thermograph (fig. 2) is of the mercury-in-steel bulb and capillary type, Negretti & Zambra's Model B. A brass well protects the bulb. The bulb has a capacity some 150 times that of the 10 feet of fine capillary, the bore of which is but 0.007 inch. For a change of temperature of the capillary of 20°, therefore, an error of a little over 0.1° only is introduced. The capillary ends in a Bourdon tube, the curvature of which changes with the pressure of the mercury. The pen arm is fastened onto the free end of the Bourdon tube and is unencumbered by levers. The pen rests lightly on the drum, for the pen arm at its base has a hinge that slants enough to allow part of the weight of the pen and arm to bear on the record sheet. The sheet in this instrument is 5.8 inches high and 16.2 inches long, providing a fairly open scale both for temperature and time.

Tests of the thermograph were made by S. P. Fergusson and C. F. Brooks at Washington, April 27, 1928, showing it to read too low, by 0.5° F. at 67, 0.4° at 77, and 0.3° at 85. Another, by H. B. Boyer, July 28, after the instrument had been installed on the *Henry M. Flagler*, showed the thermograph 0.5° too low at 88.7. A series of 30 comparisons by C. F. Brooks, during a round trip across the straits, April 8–9, 1929, between the temperature of the water coming from the faucet on the intake pipe and that being recorded by the thermograph, showed the thermograph too low at temperatures from 76° to 79° F. by 0.6° F. 3 times, 0.7° 24 times, and 0.8° 3 times. After allowing for the sheet having slipped up from the basal flange 0.2° of scale, the error averaged 0.5°, essentially as before. Since these tests in April, C. H. Stanton has compared the thermograph record with a calibrated thermometer each week. Without exception during the past 10 months at temperatures between 75° and 90° F. the thermograph has continued 0.5° F. too low. No attempt has been made to adjust the instrument for so small an error, the stability of which makes correction of tabulations easy.

How the thermograph is installed.—The installation of an instrument of this kind on a steamship is not always practicable. The bulb must be placed in flowing water and the recorder set close by so there will not have to be too much capillary. To fix an exposure on the outside of a ship is a dry-dock job. The main intake for the condensers provides a great volume of water immediately from the sea, and has been found to be the most satisfactory position for the thermograph bulb.[4, 5, 6]

On the *Governor Cobb* installation was not practicable because nearly all the intake pipe is in the bilge and below the deck plates; the only available point was where the steam enters the condenser. Moreover, the pipe is of cast bronze, which, if tapped, would require brazing in dry dock. On the *Henry M. Flagler*, however, no such difficulties presented themselves. On the inner portion of the sea-valve casting, where the intake pipe joins it, a 1-inch hole was drilled to admit the well in which the steel bulb closely fits. (Fig. 3.)

[2] Charles F. Brooks. Observing Water-Surface Temperatures at Sea. MONTHLY WEATHER REVIEW, June, 1926, 54: 241–254, inclusive, discussion by several, and comment by F. G. Tingley.

[3] Charles F. Brooks. Reliability of Different Methods of Taking Sea-Surface Temperatures. Jour. Washington Acad. Sci., Dec. 4, 1928. 18: 525–545.

[4] Sir Frederic Stupart, J. Patterson, and H. Grayson Smith. Ocean Surface-Water Temperatures—Methods of Measuring and Preliminary results. *Bull. of the National Research Council*, No. 68, Washington, 1929, pp. 76–88, especially 78–80, figs. 1 and 2.

[5] Charles F. Brooks. Notes on the Extension of the Use of Sea-Water Thermographs, and on How They have been Installed, in annual reports of the Committee on Submarine Configuration and Oceanic Circulation, National Research Council, 1927, 1928, 1929, and 1930 (mimeographed).

[6] Footnote 3, p. 535.

Mr. Stanton describes the position of the bulb as follows:

It is placed in the suction pipe to the upper sea valve to the circulating pump of the main condenser on the pump side of the valve about 2 feet from the skin of the ship. We have a 12-inch centrifugal circulating pump which runs at about 225 revolutions per minute; there is no velocity lost in the speed of the water, as the pump is about 6 feet below the water line and the water flows to the pump. The sea cock is 6 feet below water line.

From the bulb the capillary follows a rib of the ship at about 10 inches from the skin on a slant upward to the recorder on a shelf. The recorder is bolted to a shelf which is itself bolted to the skin of the ship and is so placed that the pen arm is in a fore-and-aft position. (See fig. 3.) Owing to the damping by the sea, the effect of the engine vibration of the ship on the fineness of the record is negligible. But severe rolling doubles or trebles the 0.1° ordinary scale width of the record line. This is due in part to the pen swinging on its hinges away from the drum and back onto it. In mid-November, 1928, the pen swung against the glass window of the case and stuck, causing loss of record. The ship was at times rolling 36°, Mr. Stanton reported. After the ink was removed from the back of the pen and the glass cleaned no further trouble of this sort was experienced. On one of the trips the intake rolled out of water so much that the recorded temperature rose to 4° above that of the sea.

What the thermograph record represents.—The sea cock through which the condenser intake water enters is 6 feet below the surface on the average. This depth varies an average of 1 foot and a maximum of 2 feet [7] with the load of freight cars and a great deal with the amount of roll, possibly 8 feet at 35°, from 2 feet down to 10 feet below the surface. There is almost always enough ground swell to bring the intake now and then to appreciably less than the 6-foot depth. Thus the water is drawn from different levels of the top 8 or 10 feet. In rough weather and at night, when the water is well stirred, the temperature of the entire layer is the same as that at the surface, but on a calm sunny afternoon the water near the surface becomes 2° to 4° F. warmer than at a depth of several feet.[8] The afternoon of April 12, 1929, the record ranged over a degree from minute to minute, with an extreme of 1.7° F., apparently owing to the higher temperature of the surface though such differences may exist horizontally as well as vertically.[9] Similar ups and downs, amounting to 2.3°, July 2, and 2.4°, August 12, 1929, occurred in quiet weather. On the other hand, on a sunny day with a wind of Beaufort 2–3 and no appreciable sea, five surface observations by C. F. Brooks with the large canvas bucket, between 12:55 and 3:00 p. m., April 9, 1929, gave temperatures 0.2° below, no difference, and 0.1°, 0.1°, 0.1° F. above the corrected indication of the thermograph, or an average of no difference.

For 16 days when the thermograph record showed afternoon temperatures appreciably higher than the night temperatures, and for which bucket observations and wind data were available on the same ship, the following tabulation shows that in all but the very quietest weather the thermograph record indicates the surface temperature.

TABLE 1.—*Difference between bucket and thermograph records of sea temperature between 1:45 and 4:45 p. m. on days with large diurnal range of surface water temperature, April to August, 1929, between Key West and Habana. Steamship "Henry M. Flagler"*

Wind velocity

Wind velocity	Number of—		Bucket temperature minus thermograph temperature at time of bucket observation						
			For mean reading of thermograph			For lowest swing of thermograph, mean	For highest swing of thermograph		
	Days	Bucket observations	Mean	Least	Most		Mean	Least	Most
			° F.	° F.	° F.		° F.	° F.	° F.
Very light (Beaufort 0)	6	11	1.0	0.2	2.6	1.4	0.6	−0.5	2.3
Light (Beaufort 1)	7	12	−.6	−1.7	.3	−.2	−1.0	−2.9	.1
Moderate (Beaufort 2)	3	6	−.7	−2.0	.8	−.3	−.8	−2.4	.3

Table I shows that on the calm days the temperature obtained with the canvas bucket averages 1° above that shown by the thermograph for water 6 feet below the surface, and that the surface temperature as observed in a sample drawn up in a bucket may be as much as 2.6° F. warmer than the intake water. The thermograph trace, however, shows marked fluctuations on such quiet days, which range on the average from 0.6° to 1.4° F. below the surface sample. The highest temperature recorded by the thermograph within a few minutes of the time of bucket observation ranges on calm days from 2.3° below the bucket temperature to 0.5° above.[10]

With even a light wind, the surface samples by bucket usually show temperatures lower than the intake thermograph by a mean of 0.6° and an extreme of 1.7° F. The depression of bucket temperature below the highest swing of the thermograph pen is nearly 3°. Corresponding values for moderate winds are almost the same. The fact that the bucket temperature is some half degree lower than the intake temperature when there is enough wind to stir the water is in accord with other observations,[11] and suggests that if, as likely, this cooling also affects the samples on calm days the actual temperatures of the surface range from 1° to 3° higher than those at the depths through which the car-ferry intake swings. Thus the thermograph records from the *Henry M. Flagler* are truly representative of the surface temperatures except on the rather rare calm days, when, during midafternoon hours, the surface temperatures may run from 1° to 3° above the intake.[12]

Notations on the thermograms.—Since the temperature of the water in the intake pipe is recorded continually

[7] Ordinary draft before loading is 12½ feet, average loaded draft, 14½ feet; maximum load draft, 16 feet, which is seldom reached.

[8] See references in footnotes 2, 3, and 5.

[9] Cf. Discussion of paper by Charles F. Brooks and Hazel V. Miller. Gulf-Stream Temperatures in the Straits of Florida. Bull. Amn. Met'l Soc., May 1929, 10: 107–110. Ref. top p. 110.

[10] This warmth on the surface is in accord with P. M. van Riel's paper, The Influence of Sea Disturbance on Surface Temperature (Kon. Ned. Met. Inst. Med. en Verh. 30, 1929. Note in Met. Mag. London, Feb., 1930, pp. 20–21. Surface temperatures average about 0.5° to 1° F. higher on quiet than on moderately rough days.

[11] See references in footnotes 1 and 2.

[12] Cf. footnote 4 and G. F. McEwen. Significance of Water-Temperature Measurements Not Made Exactly at the Surface. *Jour. Wash. Acad. Sci.*, Dec. 4, 1929, 18: 545–546.

FIGURE 5.—June 30 to July 7, 1929. An exaggerated example of the contrast in temperature in bright, quiet summer weather.

FIGURE 6.—June 8 to 15, 1929. Note the higher temperatures in shallow water and the diurnal range of two or three degrees.

FIGURE 7.—August 11 to 18, 1929. Late summer temperatures; shallow waters less contrasted with the deep.

FIGURE 8.—August 6 to 11, 1928. Even distribution of temperature in cloudy disturbed weather while hurricane was passing at a distance

FIGURE 9.—September 22 to 29, 1929. Regular course of temperature first of week replaced by falling temperature as hurricane passed close by on September 28

FIGURE 10.—October 6 to 13, 1929. Diverse sea temperatures in cool week after stirring by hurricane.

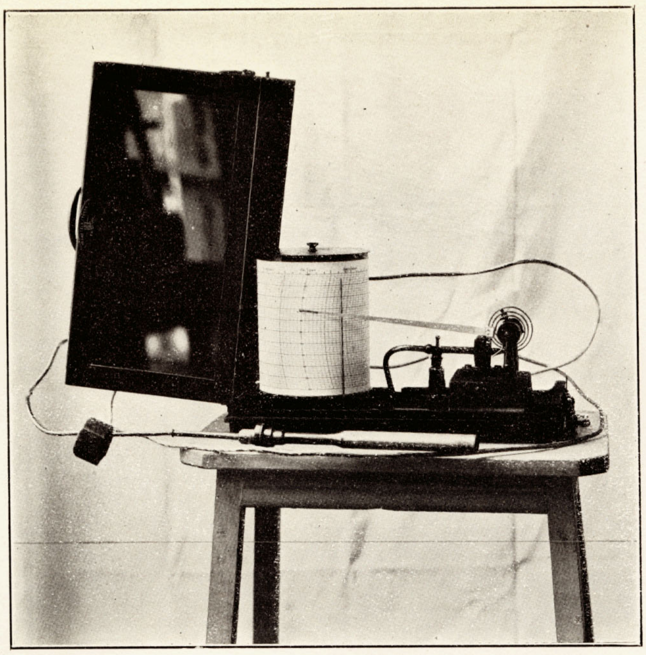


FIGURE 2.—The Negretti & Zambra, model B, sea-water thermograph. The bulb and capillary are filled with mercury. The coil on the recorder is a Bourdon tube, which changes curvature with change in pressure of the mercury. The pen arm is fastened directly to one end of the Bourdon tube, and is hinged to provide light contact with the drum

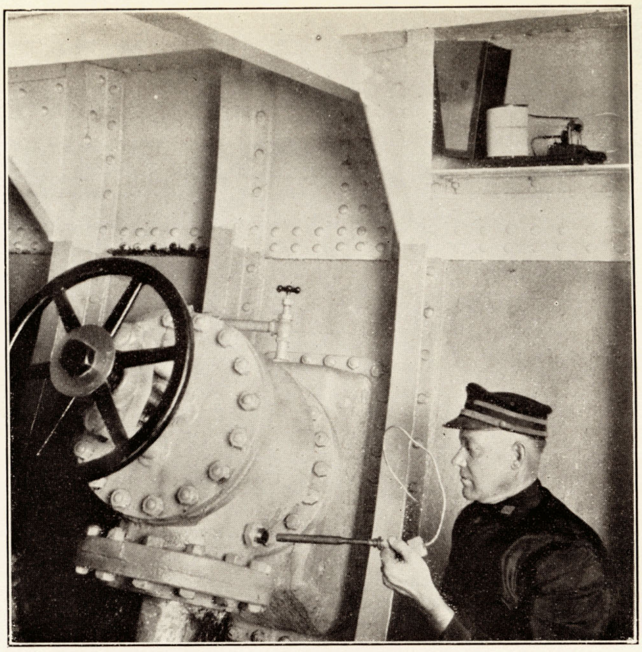


FIGURE 3.—The bulb, capillary, and recorder of sea-water thermograph on S. S. *Henry M. Flagler*, C. H. Stanton, chief engineer, Peninsular & Occidental S. S. Co. The bulb, in Mr. Stanton's hand, fits into a well that projects across the rapidly flowing stream of seawater which is pumped into the condensers of the steamship

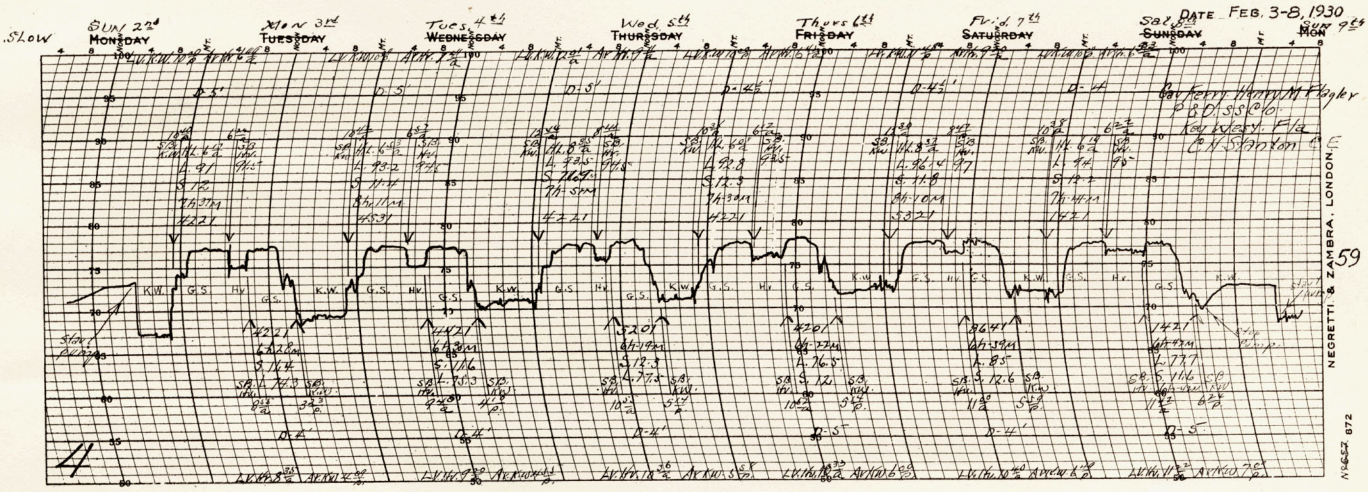
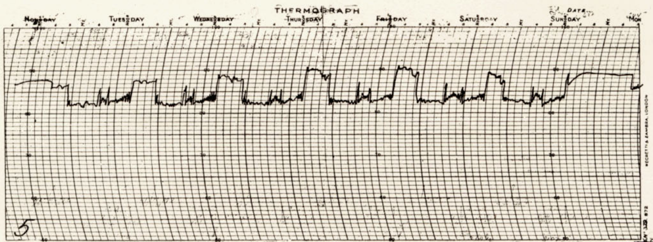
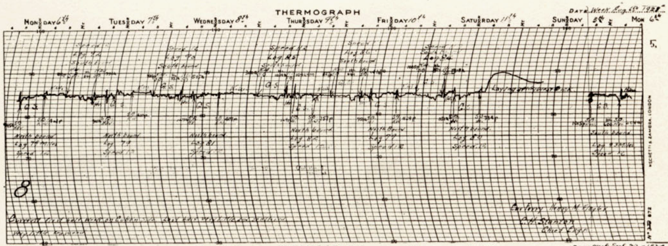
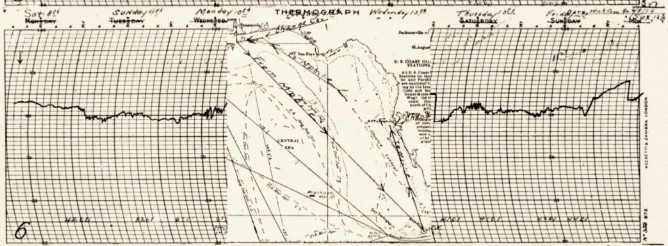
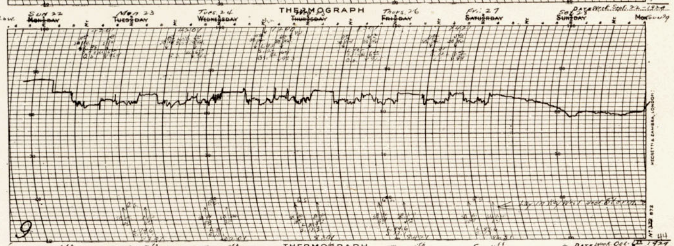


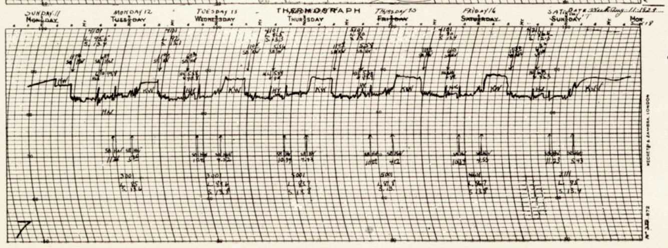
FIGURE 4.—A thermogram illustrating the notations used to indicate the supplementary data for the Key West to Habana seawater thermograms. The weather notations indicate southeasterly to southerly winds from the 2d to the morning of the 7th, with accompanying rising temperatures of the sea surface. At the end of the week the wind turned north and temperatures began to fall. Note the strong northwesterly wind of the 7th, and the 8 miles greater than usual logged mileage on the daytime return trip

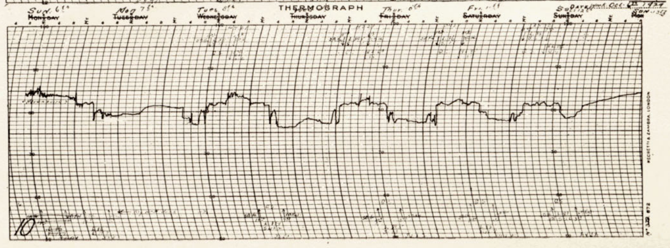


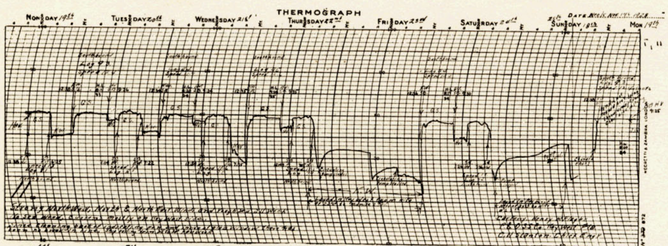








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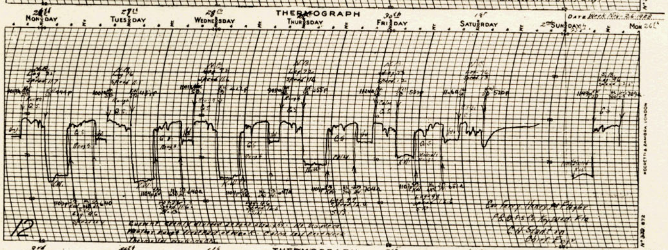
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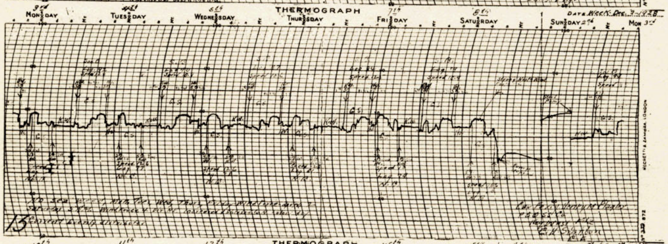
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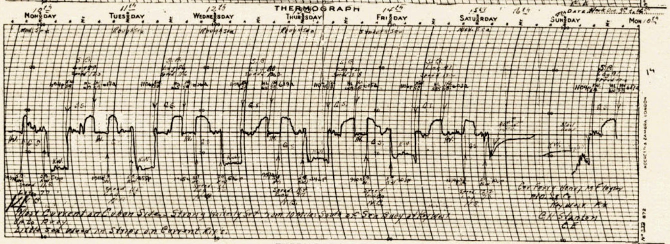
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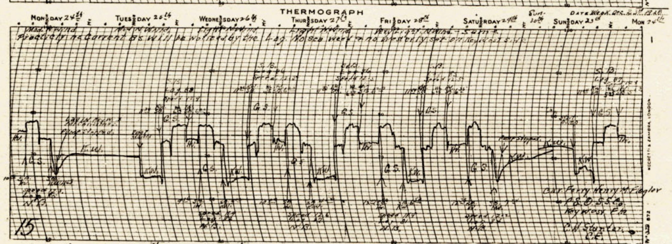
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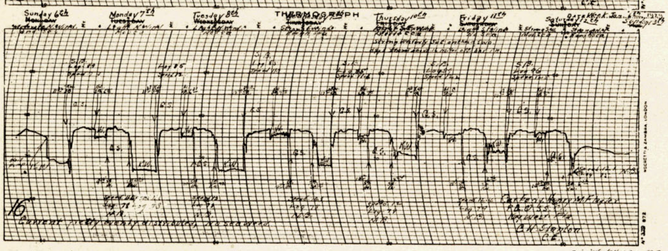
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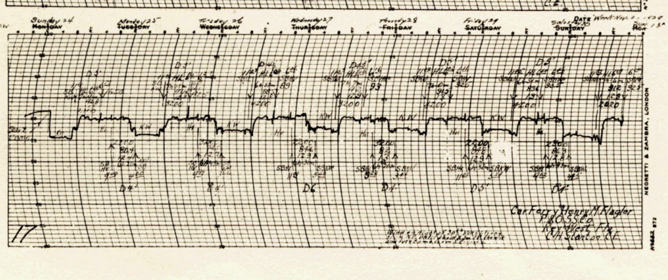
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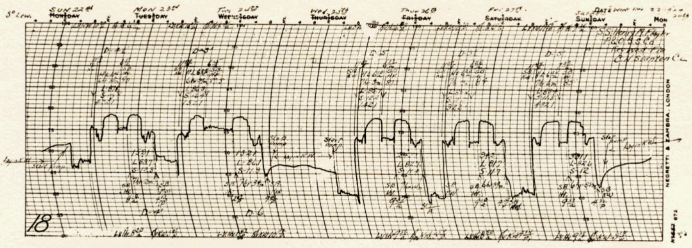
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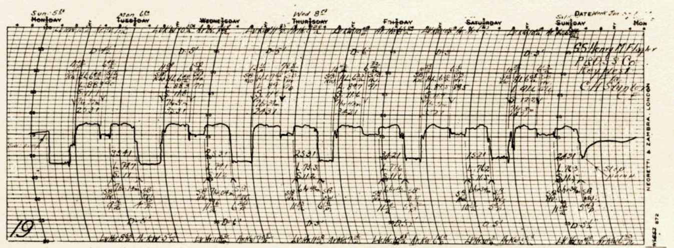
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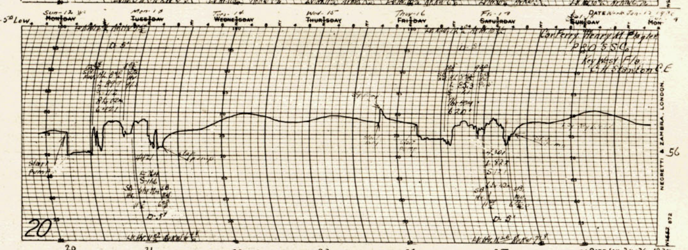
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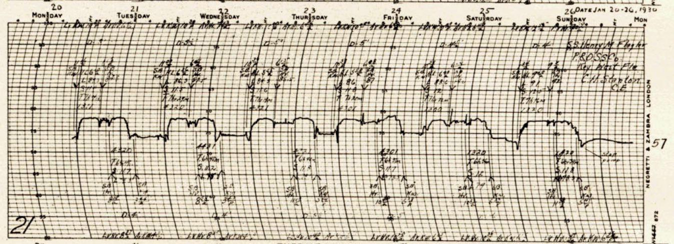
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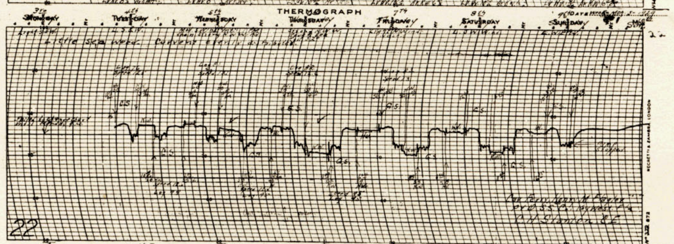
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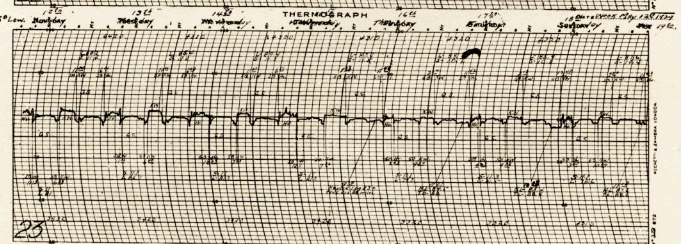
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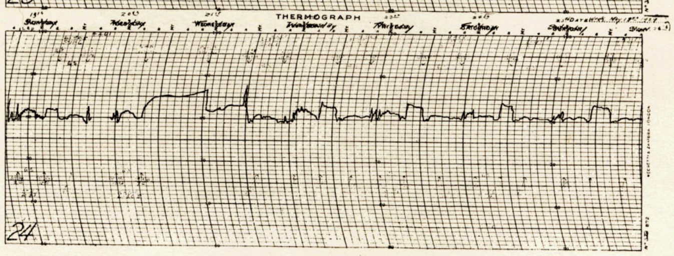
THERMOGRAPH
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whether or not the ship is underway, notations as to dates and hours of arrival and departure of the ship are essential for accurate tabulation and use of the records. Mr. Stanton now gives the following information on the thermograms (see fig. 4):

Date.

Circulating pump started and stopped.

Hour and minute of departure and arrival at dock and when passing Key West sea buoy (S. B. K. W.) and Habana sea buoy, Morro Castle abeam (S. B. Hv.).

That portion of the trace showing the water between the Key West and Habana sea buoys (G. S., after Gulf Stream), and those while ship is at dock at Key West (K. W.) and Habana (Hv.).

Hour and minute when ship hauls in the patent log on arrival off Habana (H. L.). This is of special significance when the ship is on second run and must wait for the first ship to leave the harbor.

Logged mileage, sea buoy to sea buoy (L.), also, when ship stops off Habana, logged mileage from Key West Sea Buoy to hauled log position (H. L.).

Average speed of ship in knots from sea buoy to sea buoy, i. e., logged mileage divided by the number of hours ship was on its course (S.).

Depth of intake (D.), to nearest half foot.

Extended periods when ship is at dock either in Habana or Key West are noted.

Wind direction and force, roll of ship, and amount of seaweed each trip, a series of four numbers according to the following scales:

Wind direction (Beaufort notation)	Wind velocity (Beaufort scale)	Roll of the ship (Stanton's scale)	Amount of Gulf weed (Stanton's scale)
1=N. 2=NE., etc. 8=NW.	0=Calm. 1=Light airs, etc., to. 6=Strong breeze. 7=Moderate gale which is limit of safety for this car ferry.	0=No roll. 1=1 to 5 degrees roll. 2=5 to 15 degrees roll. 3=15 to 25 degrees roll. 4=25 to 35 degrees roll. 5=Above 35 degrees roll.	0=No weed. 1=Moderate presence of weed. 2=Lots of weed.

Clock errors: Pointers from sea buoy times to temperature line are as accurate as possible, and engineroom clock time is checked against thermograph every day.

Thermograph temperature checked every week by calibrated thermometer, and notation of variation made on upper left-hand margin of chart.

Weather or current conditions of special note are summarized on front or back of chart.

THE TEMPERATURE PROFILE AT DIFFERENT SEASONS

The temperature profile of the surface waters between Key West and Habana is a constantly changing one. At the different seasons, however, it has certain features characteristic of the time of year which tend to recur day after day. In summer, high temperatures at Key West and flatness of the Gulf Stream profile are characteristic. In winter, low temperatures at Key West, moderate ones in the northern portion of the Straits and appreciably higher ones in the southern are usually in evidence. In spring, there are alternations between winter and summer types; and in autumn irregular types occur, especially after the passage of a hurricane. In the following paragraphs samples of profiles will be presented and some interpretation made. A detailed study of the distribution of temperatures and its relation to the previous and present weather, however, must await a larger body of records.

Summer temperature profiles.—The thermogram for June 30 to July 7, 1929 (fig. 5), is an exaggerated example of the contrasts in temperature that commonly develop in summer. The high temperatures of the more quiet waters of Key West Harbor and reefs and of Habana Harbor and its narrow entrance, on either side are sharply differentiated from the somewhat lower ones of the moving and stirred Gulf Stream. The spires of high temperature in Habana Harbor and the plateaus of still higher temperature in Key West Harbor are features of the temperature profiles practically throughout the warmer half year. The Habana maxima occur in the central portion of the larger part of the harbor, and are higher than the temperatures at the dock, because of the dock shadows and greater stirring near shore.[13] The maxima between Key West sea buoy and the harbor are, similarly, in the more heated shallow water. Thus, on the afternoon of April 10, 1929, the writer observed a temperature rise from 78.3° F. in the blue water to 79.8 as the car-ferry *Joseph R. Parrott*, on which he was riding, passed a sharp boundary into green water half a mile inside the sea buoy which is at the 20-fathom line.

Close by these prongs of high temperature on the Habana side are sharp depressions, best developed in fig. 5 on July 6, which mark the contact of swell and current [14] with the bottom a short distance from the shore. Eye observation of intake temperature every two or three minutes by C. F. Brooks on the *Henry M. Flagler*, April 9, 1929, showed the lowest temperature about a mile from the sea buoy at the entrance of Habana Harbor, or somewhat under a mile off-shore.

[13] Water in Habana Harbor has practically no circulation, as there is but one narrow entrance and very few shallow spots, being all dredged out and deep (average 25 feet right up to land). The tides here average less than a foot (0.9 foot) mean, 1.3 feet maximum according to "Tide Tables United States and Foreign Ports, 1930," U. S. Coast and Geodetic Survey, Washington, D. C., 1929).

[14] John E. Pillsbury. The Gulf Stream. Methods of investigation and results of research. Report of the Superintendent, U. S. Coast and Geodetic Survey, year ending June 1890, Appendix 10. Washington, 1891, pp. 461–620. Refer to p. 596.

FIGURE 11.—November 18 to 25, 1928. A norther cools the harbors and begins to cool the Gulf Stream.

FIGURE 12.—November 26 to December 2, 1928. Cool streaks of falling temperature in Gulf Stream after a strong norther.

FIGURE 13.—December 2 to 8, 1928. A quiet week, with recovery of harbor temperatures and widening of warm portion of Gulf Stream.

FIGURE 14.—December 9 to 15, 1928. Another norther temporarily reduces width of warm portion of Gulf Stream from 40 to 15 miles.

FIGURE 15.—December 23 to 29, 1928. A week of much contrast but practically no current.

FIGURE 16.—January 6 to 12, 1929. Mid winter profiles—cooler north than south. (Cf. fig. 19.)

FIGURE 17.—November 24 to December 1, 1929. A quiet week in late fall with Gulf Stream temperatures as high as 81 running into the early days of December.

FIGURE 18.—December 22 to 28, 1929. A week of unusually cold northerly winds with consequent falling temperatures. Note the low temperature of 58.5 at the northern margin of the Gulf Stream the night of December 25–26, while only a mile or two away the temperature reaches 74. On this crossing the range was 20° in sea temperature. (Cf. figs. 12 and 15.)

FIGURE 19.—January 5 to 11, 1930. A slow recovery in sea temperature. Note that the usual cool northern portion of the Straits is virtually absent, though on the 11th a cool streak begins to develop appreciably. (Cf. fig. 16.)

FIGURE 20.—January 13 and 17, 1930. A wide band of cool water far from shore January 13 as center of a westward moving low passes, with brisk shifting winds.

FIGURE 21.—January 20 to 26, 1930. A quiet period in winter resembling springtime conditions.

FIGURE 22.—March 2 to 10, 1929. A springtime curve during a period of cool winds that temporarily reduced temperatures.

FIGURE 23.—May 12 to 19, 1929. The relative coolness of the north portion is still in evidence though scarcely less marked than the cool weather on the Cuban side. The flatness of this curve goes with a windy week.

FIGURE 24.—May 19 to 26, 1929. With cloudier conditions the Key West temperatures rose 2° and the Gulf Stream 10°, while daily ranges increased to 2° or 3°, a summer time condition.

A prominent feature of the afternoon portions of the daytime return trips toward Key West is the widening of the temperature line to 1 to 2 or more degrees owing to considerable variations in temperature within intervals of a few minutes. The lowest temperatures on these swings of the pen are a half to 1 degree higher than the temperatures recorded for the same positions during southbound trip the preceding night, and this half to 1 degree rise appears to represent about the warming that has occurred during the day to a depth of 8 or 10 feet where the intake, with the rolling of the vessel, would probably catch its coolest water. The higher portions of the swings of the pen represent practically surface temperatures, as shown in the discussion of Table 1. July 1, the only calm day of the week, has the largest range of these afternoon swings of temperature—2.7°.

Even till midnight the waters remain fairly warm on the surface and spots or belts of cooler and warmer water seem to develop. On the nights of July 1 and 2 a small body or streak of warm water about 2° above the general run of temperature was encountered 6 and 8 miles off the Key West sea buoy.

The round trip of the *Henry M. Flagler* to Mobile early in June, 1929 (Fig. 6), showed the characteristic higher temperatures in shallow water between Key West and Tampa sea buoy, and a fall of 2.5° F. when the 10-fathom curve off Tampa was passed into deeper water. The diurnal range in temperature in the open Gulf June 9, 13, and 14, was about 2°, with an extreme range of 3° the 13th. The highest temperatures occurred at 2:30, 3:55, and 3:30 p. m. on these days and the lowest between 5 and 9 a. m. A southeast wind of force 4 as the ship approaced Key West the evening of the 14th seems to have been responsible for the upwelling of cooler water outside the 10-fathom line, for the temperature fell from 81.5° F. about 35 miles from the sea buoy to 79.8° F. 20 miles out, where the water is 13 fathoms deep, then rose rather evenly to 83.8 at the sea buoy and kept at this temperature to Key West. (Fig. 6.).

The thermogram of August 11–18, 1929 (Fig. 7), obtained by Mr. H. L. Kissen, chief engineer, during Mr. Stanton's vacation, shows late summer temperatures. With the sun less high in the sky and the general level of Gulf Stream temperature near its maximum, the temperatures in August are less contrasted than in early July. The same features of high Key West temperatures, warm Habana Harbor, and warmer afternoon than night temperatures are in evidence.

The thermogram of August 6 to 11, 1928 (Fig. 8), shows the flatness of cloudy disturbed weather while a hurricane is passing at a moderate distance. At the beginning of this week the storm was centered over the southern Bahamas; the 7th it was nearest Key West, being over the Gulf Stream east of Miami. The next two days the storm was traveling northwestward through Florida. Habana, appreciably farther from the storm track than was Key West, shows the ordinary high temperature prongs of the open portion of the harbor. The daily range of Gulf Stream temperature was kept small, about 0.5° F., till near the end of the week, when it increased to 1° as the hurricane drew away.

Autumn thermograms.—A hurricane that comes close enough to stir the waters vigorously as well as to spread its dense cloud canopy lowers harbor-water temperatures considerably [15] and Gulf Stream temperatures appreciably.[16] The hurricane of the end of September, 1929, passed close by Key West on the northeast, the center at its nearest point being but 30 miles away. The (5-min.) average wind velocity at Key West on September 28 reached 66 miles an hour, with gusts estimated at 80. The thermogram for September 22 to 29, 1929 (fig. 9), shows a fall of Key West Harbor temperature of 1° as the hurricans approached, then a 24-hour fall of 5° as the storm passed. While the ship was in Key West Harbor during the storm this record of the harbor temperature was obtained. After the storm a cool spot appeared in the straits about two-fifths of the way from Key West to Habana, and, with little current in the stream, stuck there for several days, moving northward and disappearing October 12. (Fig. 10.) A squally and rainy week, October 6 to 13, 1929, reduced Key West temperatures 5° and Habana's 2°. The cool spot or streak was some 5 miles wide the night of the 9th or 10th and had a temperature exactly the same as that at Key West, suggesting that this water had come from the reefs or the shallow eastern part of the Gulf of Mexico, perhaps pushing along in the faster current outside the generally quiet water immediately south of the keys, and thereby appearing as a cool streak.

Strong northerly cool winds blowing over the warm waters of the reefs and Straits bring notable changes in a short time, exceeding the cooling by a hurricane. The effect of the norther of November 20–28, 1928, has already been described.[17] The thermogram of November 18–25 (fig. 11) shows the rapid fall of Key West temperature, the less precipitate decline of Habana Harbor temperature and the rather slow cooling of the Gulf Stream as a whole. The following thermogram, November 26–Dec. 2 (fig. 12), shows the appearance of marked cool streaks in the Gulf Stream on the 7th day of the northerly wind, and the increasing invasion of cool water during the several days following. M. Idrac's observations of the yacht *Jamaica* of temperatures to depths of 1,000 meters on a line north from Habana November 24–25 and again December 1 show that the decrease in temperature was more than a surface phenomenon.[18] Between the observations of Nov. 25 at 28 miles north of Habana and those of Dec. 1 at 24 miles north of Habana, the temperature at the surface fell 0.8 deg. C., that at 200 meters fell 3.7 deg. C., that at 400 m., 2.6 deg., and that at 600, 0.7 deg.[19] In other words, at the mean position of the axis of the Gulf Stream (according to Pillsbury), the temperature of the water to a depth of a quarter of a mile fell 5° F., at a depth of nearly one-half mile the temperature fell about 1°. This does not mean that such a great mass of water lost enough heat in this short time to effect this fall in tem-

[15] I. R. Tannehill in unpublished manuscript. The cold-water trail of the hurricane, 1923, shows that in four hurricanes, 1882-1886, the sea temperature at a depth of about 12 feet in Galveston Harbor was 1° to 2° F. cooler for the 6 days after a hurricane than for the 6 days before, the fall in temperature for the storm of August, 1886, amounting to 6.4° F. from 2 days before the storm (89.1° F.) to the day of the storm (82. 7 F.). He ascribes this cooling to increased tides as well as to cloudiness, rainfall, and wind stirring. The average change between low and high tide he found was ¾° F.

[16] Hazel V. Miller in abstract of paper on Temperature Variations in the Gulf Stream in the Straits of Florida, 1917-1921, *Bull. Am. Met'l. Soc.*, 1926, 7: 88, states that "Noteworthy is the depression of about 2° F. in temperature during the passage of a hurricane through the straits in September, 1919."

[17] Charles F. Brooks. A norther cools the Gulf Stream. *Bull. Am. Met'l. Soc.*, Mar., 1929, 10:70–72.

[18] P. Idrac. Sur quelques singularities du Gulf-Stream. Comptes Rendus, (Paris) Acad. Sci., Feb. 25, 1929, 188:644. Repr., without the diagrams, in Mo. Weather Rev., May, 1929, 57:206.

[19] P. Idrac. Personal communication with detailed data of the observations on which the diagrams in *Comptes Rendus* were based.

perature, but rather, as indicated above, that the north wind had driven more cooler water in the Straits.

Winter temperature profiles.—After a quiet week in which Key West temperatures came back to 77° F. and the warm portion of the Gulf Stream took possession of half the Straits (fig. 13), another norther setting in December 8 reduced the warm portion of the current to only one-fifth the width of the Straits, December 10 (fig. 14), the reduction from half the Straits (40 miles) to one-fifth (15 miles) taking place between 4 a. m. and noon that day. The warm portion recovered three-fourths of its former width (or 30 miles) the following night and all of it by the end of the week, but its temperature became nearly 1° F. lower than before. Not all such variations may be due to winds, for Pillsbury has emphasized the variations in direction from which the water enters the Straits under different tidal phases. He also ascribes the lesser thermometrical variations to "an interference of successive tidal impulses meeting the obstruction of the shore, whereby a vibratory motion is produced on the ocean's surface attenuating or concentrating the warm surface layer." [20]

Whether such rapid changes take place in the position of the warmer portion of the Gulf Stream off our Middle and North Atlantic seaboard is still to be determined from a study of the temperature profiles already at hand. Cursory inspection, however, coupled with years of bucket observations, indicate that changes in the position of the Gulf Stream amounting to more than 50 or 100 miles do not occur, and that such small shifts can not in anywise be considered as a "change in the course of the Gulf Stream" so commonly imagined by those who would ascribe any extraordinary weather phenomenon to such a hypothecated departure of this great ocean stream from its established position.

After further north winds at Christmas time the northern half of the Straits reached its lowest temperatures, averaging 73° F., and, in a cool streak, between the northern portion and the warmer southern, running down to 70.6° F. December 27. (Fig. 15.) Such cool streaks may be due to masses of cool water from the reefs, or to upwelling between currents of different speeds, the southern, presumably the stronger and, therefore, deflected more to the right, and away from the northern in its eastward movement. But, Mr. Stanton notes that there was practically no current this week, the southbound logged mileages averaging only 3 miles more than the northbound, when ordinarily there is a difference of 10 or 15. The persistence of the temperature profile practically unchanged in even the details of its shape was probably due to the ship passing through much the same water day after day.

The week of January 6 to 12, 1929 (fig. 16), provides good samples of winter temperature profiles, which are, in several respects, the reverse of the summer. The shallow waters of Key West Harbor and shoals are decidedly cool, while Habana Harbor is somewhat cooler than the Gulf Stream temperatures. The Straits are now coolest on the northern edge, while in summer they were warmest there. The temperatures of the Gulf of Mexico, the waters from which flow more into the northern portion of the Gulf Stream [21] are higher in summer and lower in winter than the Caribbean waters that generally feed the southern part of the Stream,[22] whereas some apparently detached warm bodies or narrow currents of water were noted near Key West on the summer thermograms (July 1 and 2), cool streaks appear in the winter in the same vicinity, most prominently January 6–9, possibly detached masses of the cooler shoal water of the western keys. Just as the detached warm bodies were not so warm as the Key West Harbor, which represents the shoal water temperature, so these detached cool bodies are not so cool as the harbor water.

Winter profiles, 1929–30, were strikingly like those of 1928–29, just described. In the week ending December 1 (fig. 17) and till December 4 the temperature of the northern quarter of the Straits was generally 77 to 78, while the southern three-quarters was as high as 81° F. In a strong northwesterly wind from December 3 to 5, the Key West Harbor temperatures dropped from 75 to 68, the north portion of the Straits from 77 to 75, and the warm three-quarters of the Straits from 81 to 79.5 and, by the 6th, to 79. Habana Harbor cooled from 80 to 76. Southerly winds at the end of the week raised the temperature of the warmer portion of the Straits to 80, where it stayed till the 11th. A slow fall ensued. Then, on the 19th, a strong cool NW. wind (maximum velocity 32 miles per hour at Key West) again drove temperatures downward. The morning after this blow, three deep nicks, showing water 2° to 4° cooler than on either side of each nick, appeared in the temperature profile of the northern half of the Straits.

After a brief respite, the following week, December 22 to 29 (fig. 18), was noteworthy for its unusually cold northerly wind. The mean daily air temperatures December 24 to 26 were 58, 60, and 59° F., or 11 degrees under the December normal. Key West Harbor sea temperature fell from 69, on the 23d, to 60, on the 26th. The cool portion of the Straits (at that time the northern two-fifths) fell from 75 to 73. The warm section was but little affected, falling from 79 to 78.5. Habana Harbor cooled from 76 to 73.5. The thermogram of this cool week looks very much like that of December 23–29, 1928 (fig. 15). The lowest temperature, at or near Key West Sea Buoy, was 58.5° F. at 11 p. m. December 25. This was 3° under the minimum of the winter of 1928–29.

With the return of normal mild weather with moderate to brisk NE. to E. winds, the cool portion of the Straits became very much restricted, in the week of January 5 to 11 (fig. 19 almost a replica of fig. 16, January 6–12, 1929). On the night of the 10th to 11th, however, as the wind backed to N. with the approach of a subtropical Atlantic low from the east, a marked cool streak made a temporary appearance in the northern portion. Its lowest temperature, 72.4, was in marked contrast with the 76.6 and 77.6 on either side. With the wind again in the NE., on the daytime return trip the 11th, the cool streak had disappeared except for a small nick in the thermogram. On the following trip, the 13th (fig. 20), as the center of the low was passing through the Straits, with brisk shifting SW. to SE. winds, a wide segment of cool water, about 20 miles wide appeared between warmer water near the north portion of the Straits and the warm water in the middle. The minimum temperature of 71.5 was sandwiched between maxima of 77.1 and 77.6. After disturbed weather—two days with southerly winds and two with NW. to N. the next trip, on the 17th, revealed the more usual winter time cool water in the northern quarter, and warm in the southern three-quarters. Warmer water had recaptured part of the Straits previously occupied by cooler.

In the more settled moderate weather of January 20–26 (fig. 21) the thermogram was very much like those of spring. On some days as much as 1° diurnal range of temperature appeared. With further wintry weather,

[20] Pillsbury, op. cit., p. 596.
[21] Ibid., p. 609.
[22] H. V. Miller, loc. cit., p. 87.

however the following thermogram resumed a strongly contrasted appearance. The rather quiet week of February 2–9 (fig. 4) had rising harbor and Gulf Stream temperatures till the 7th, after which a cool wind drove temperatures down again. On the warmest days, February 5 and 6, an appreciable diurnal range again appeared.

Spring profiles.—The week of March 3 to 10, 1929 (fig. 22), while showing a cooler northern half of the Gulf Stream than some winter profiles, already began to exhibit the warm shoal-water spires of summer. In the earlier part of the week, Key West and Habana temperatures were, as in summer, above those of the Gulf Stream. But a strong northwest wind the 5th and 6th depressed Key West Harbor temperatures 6° and Habana 2°. At the same time, the cool-water portion of the Gulf Stream was widened at the expense of the warm, owing, apparently, to a greater contribution of water from the Gulf of Mexico.

In the week of May 12 to 19, 1929 (fig. 23), the relative coolness of the northern portion was still in evidence. It was scarcely less marked, however, than the cool water on the Cuban side. The stream was warmest in the middle. As the notations on the thermogram indicate, this was a windy week, with east and southeast winds of force 3 and 4, and with a sea that kept the ship rolling considerably. Thus, it is not surprising to find rather smooth profiles and no more than 0.5° F. daily range of temperature. In spite of the wind, however, Key West Harbor temperatures continued a degree or two above those of the Gulf Stream. With the quieter conditions of the following week (fig. 24), Key West temperatures shot up 2°, and the surface of the Gulf Stream rose 1°, while daily ranges increased to 2° or 3°. The highest temperatures, May 22 and 23, occurred between 2:30 and 4:00 p. m.

Five temperature, density, and salinity profiles run across the Gulf Stream between Key West and Habana and between Miami and Nassau by the writer, in April, 1929, brought out the following facts: (1) Reef and bank water was the most saline; (2) southeast Gulf of Mexico and Cuban shore water was the least saline; (3) cool streaks (?) in the left half of the Gulf Stream were the most saline parts of the stream, though less saline than the waters of the Florida keys or Bahama banks. It seems likely that the cool streaks at this time were made up of water upwelling from the more saline layer which is not far below the surface in the left portion of the Gulf Stream. In view of the lower salinity of the southeastern Gulf of Mexico, it is evident that these cool streaks could probably have had no immediate relation with the water of the southeastern Gulf north of Key West. This southeastern Gulf water, furthermore, was cooler than the lowest temperatures found in the Gulf Stream south of Key West.[23]

A detailed discussion of these observations, which included 174 with a hydrometer, and a collection of 64 samples which were later titrated at Harvard, through the kindness of Dr. Henry B. Bigelow, will be presented in a separate paper elsewhere.

CONCLUSION

The surface waters of the Gulf Stream in the Straits of Florida are diverse in temperature and are subject to considerable variations from day to day. Much of the interdiurnal variation is closely related to the weather, especially the wind, which disturbs the surface. Characteristic differences in the general shape of the surface temperature profile across the Straits seem to arise from the frequent occurrence of cool northerly winds in winter, reducing the surface temperatures on the Key West side, and from the prevalence of warm southeasterly winds in summer which raise the temperatures there. There are, however, certain fundamental differences in temperature which can not be related to the immediate weather. These will be discussed in another paper, to follow this one immediately. The thermograms have all been tabulated in detail, and weekly means have been derived for publication.

[23] Charles F. Brooks, Surface Temperature, Density, and Salinity profiles across the Straits of Florida. Bull. of the National Research Council, 1930.

INTERNATIONAL METEOROLOGICAL ORGANIZATION

ARTICLE I

The present International Meteorological Organization, created at Utrecht in 1878,[1] revised at Paris in 1919, at Utrecht in 1923, and at Copenhagen in 1929, comprises:

1. The conferences of the directors.
2. The International Meteorological Committee.
3. The secretariat of the organization.
4. The commissions of the organization.

ARTICLE II

1. The conferences of the directors have for their principal function the discussion of administrative questions and the means of execution, in order to put themselves in accord on the methods of observation and of calculation, to decide on the common work that ought to be undertaken, and to create eventually the necessary commissions; purely theoretical questions are not in the jurisdiction of the conferences.
2. The conferences are composed of the directors of the independent national meteorological networks of all nations.
3. The conferences are convoked by the International Meteorological Committee; they ought to take place at least every six years. They ought also to be convoked extraordinarily by the committee when urgent questions arise for its consideration. Convocation is obligatory when it is called for by a quarter of the members of the conference.
4. The president of the committee gives notice of the meeting by circular a year in advance to the members of the conference (and the presidents of the commissions) and causes to be designated by a vote of the committee the date and the precise place of the meeting.
5. The president of the international committee convokes directly all the members to the conferences; the secretariat establishes the list and publishes it each year after having brought it up to date.
6. The members of the conference have the right to have themselves represented if they are not able personally to take part in the conference. The substitutes ought to belong to the service represented or to be a part director of the service; he should not be a member of the conference under another title.
7. The decisions are taken by a majority of the voices of the members present, save in case a vote by countries[2] is demanded, even by a single member.
8. The conference of the directors names the International Meteorological Committee, the powers of which end at the ordinary conference following.
9. The conference chooses its president, who rules over its functions during the entire duration of the session.

ARTICLE III

INTERNATIONAL METEOROLOGICAL COMMITTEE

1. The members of the committee ought to belong to different countries and be members of the conference.

[1] So definite a statement as this must have been based on grounds not available on this side of the Atlantic; nevertheless, whatever, may have been in the minds of the directors in attendance on the Utrecht meeting of 1878, no mention is made in the proceedings of that meeting of the creation of an International Meteorological Organization. The report of the Berne meeting of 1880 bears the title "Report of the International Meteorological Committee" and thus it became the habit of some, at least, to think of the organization as a whole as that known by the title just mentioned. In commenting upon the statutes of the International Meteorological Organization, immediately following this article, the present writer adopts the view that the title, "International Meteorological Organization," was first broached at the Paris meeting of 1907, and approved at the Paris meeting of 1919.—*A. J. H.*

[2] One understands by this word all countries that govern themselves. (Example Dominion of Canada.)